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I hereby certify that this paper or fee is being deposited with the U.S. Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to Mail Stop Provisional Application, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

By: *[Signature]*  
Name: John Junkers

REQUEST FOR PROVISIONAL APPLICATION UNDER 37 C.F.R. § 1.53(c)

MAIL STOP PROVISIONAL PATENT APPLICATION  
Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

Dear Sir:

This is a request for filing a Provisional application for patent under 37 CFR § 1.53(c) entitled METHOD OF DISPENSING FUEL INTO TRANSIENT FLOW OF AN EXHAUST SYSTEM by the following inventor(s):

Full Name Of Inventor	Family Name HOU	First Given Name JASON	Second Given Name
Residence & Citizenship	City	State or Foreign Country	Country of Citizenship
Post Office Address	Post Office Address	City	State & Zip Code/Country
Full Name Of Inventor	Family Name WAGNER	First Given Name WAYNE	Second Given Name
Residence & Citizenship	City	State or Foreign Country	Country of Citizenship
Post Office Address	Post Office Address	City	State & Zip Code/Country
Full Name Of Inventor	Family Name ZHANG	First Given Name WENZHONG	Second Given Name
Residence & Citizenship	City	State or Foreign Country	Country of Citizenship
Post Office Address	Post Office Address	City	State & Zip Code/Country
Full Name Of Inventor	Family Name STEINBRUECK	First Given Name ED	Second Given Name
Residence & Citizenship	City	State or Foreign Country	Country of Citizenship
Post Office Address	Post Office Address	City	State & Zip Code/Country

Full Name Of Inventor	Family Name ANGELO	First Given Name TED	Second Given Name
Residence & Citizenship	City	State or Foreign Country	Country of Citizenship
Post Office Address	Post Office Address	City	State & Zip Code/Country
Full Name Of Inventor	Family Name WIEGANDT	First Given Name TED	Second Given Name
Residence & Citizenship	City	State or Foreign Country	Country of Citizenship
Post Office Address	Post Office Address	City	State & Zip Code/Country
Full Name Of Inventor	Family Name ANDERSON	First Given Name MIKE	Second Given Name
Residence & Citizenship	City	State or Foreign Country	Country of Citizenship
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1. ☒ Enclosed is the Provisional application for patent as follows: 22 pages of specification, and 6 sheets of drawings.
2. ☐ Small entity status is claimed pursuant to 37 CFR 1.27.
3. ☒ Payment of Provisional filing fee under 37 C.F.R. § 1.16(k) :
  - ☒ Attached is a check in the amount of \$ \$160.00.
  - ☐ Please charge Deposit Account No. 13-2725.
  - ☐ PAYMENT OF THE FILING FEE IS BEING DEFERRED.
4. ☒ The Commissioner is hereby authorized to charge any additional fees as set forth in 37 CFR §§ 1.16 to 1.18 which may be required by this paper or credit any overpayment to Account No. 13-2725.
5. ☐ Enclosed is an Assignment of the invention to \_\_\_\_\_, Recordation Form Cover Sheet and a check for \$ \_\_\_\_\_ to cover the Recordation Fee.
6. ☒ Also Enclosed: Appendix 1 (two sheets).
7. ☐ The invention was made by the following agency of the United States Government or under a contract with the following agency of the United States Government:
8. ☒ Address all future communications to the Attention of David G. Schmaltz (may only be completed by attorney or agent of record) at the address below.

## EXHAUST SYSTEM

## Technical Field

The present disclosure relates generally to diesel exhaust systems. More particularly, the present disclosure relates to systems and methods for controlling diesel emissions.

## Background

Vehicles equipped with diesel engines typically include exhaust systems that may have diesel particulate filters for removing particulate matter from the exhaust stream. With use, soot or other carbon-based particulate matter accumulates on the diesel particulate filters. As particulate matter accumulates on the diesel particulate filters, the restriction of the filters increases causing the buildup of undesirable back pressure in the exhaust systems. High back pressures decrease engine efficiency.

Therefore, to prevent diesel particulate filters from becoming excessively loaded, diesel particulate filters should be regularly regenerated by burning off (i.e., oxidizing) the particulates that accumulate on the filters. Since the particulate matter captured by diesel particulate filters is mainly carbon and hydrocarbons, its chemical energy is high. Once ignited, the particulate matter burns and releases a relatively large amount of heat.

20 Systems have been proposed for regenerating diesel particulate filters. Some systems use a fuel fed burner positioned upstream of a diesel particulate filter to cause regeneration (see U.S. Patent No. 4,167,852). Other systems use an electric heater to regenerate a diesel particulate filter (see U.S. Patent Nos. 4,270,936; 4,276,066; 4,319,896; 4,851,015; and British Published Application No. 2,134,407).

25 Detuning techniques are also used to regenerate diesel particulate filters by raising the temperature of exhaust gas at selected times (see U.S. Patent Nos. 4,211,075 and 3,499,260). Self regeneration systems have also been proposed. Self regeneration systems can use a catalyst on the substrate of the diesel particulate filter to lower the

ignition temperature of the particulate matter captured on the filter. An example self regeneration system is disclosed in U.S. Patent No. 4,902,487.

5 In addition to particulate filters for removing particulate matter, exhaust systems can be equipped with structures for removing other undesirable emissions such as carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NOx). Catalytic converters are typically used to remove CO and HC. NOx can be removed by structures such as lean NOx catalysts, selective catalytic reduction (SCR) catalysts and lean NOx traps.

10 Lean NOx catalysts are catalysts capable of converting NOx to nitrogen and oxygen in an oxygen rich environment with the assistance of low levels of hydrocarbons. For diesel engines, hydrocarbon emissions are too low to provide adequate NOx conversion, thus hydrocarbons are required to be injected into the exhaust stream upstream of the lean NOx catalysts. SCR's are also capable of converting NOx to nitrogen and oxygen. However, in contrast to using HC's for  
15 conversion, SCR's use reductants such as urea or ammonia that are injected into the exhaust stream upstream of the SCR's. NOx traps use a material such as barium oxide to absorb NOx during lean burn operating conditions. During fuel rich operations, the NOx is desorbed and converted to nitrogen and oxygen by catalysts (e.g., precious metals) within the traps.

20

### Summary

One inventive aspect of the present disclosure relates to a system or method for controlling the delivery of fuel into the transient flow of an exhaust system to control emissions. In one embodiment, a mathematical model representative of the  
25 exhaust system is used to determine, based on operating conditions of the exhaust system, a rate of fuel delivery suitable for achieving a desired result. In one example, the desired result can be to increase the temperature of a diesel particulate filter to a temperature suitable for regeneration without exceeding a temperature that may damage the diesel particulate filter.

### **Brief Description of the Drawings**

Figure 1 schematically illustrates an exhaust system having features that are examples of inventive aspects in accordance with the principles of the present disclosure;

5                   Figure 2 schematically illustrates an alternative exhaust system;

Figure 3 shows a fuel injection arrangement having features that are examples of inventive aspects in accordance with the principles of the present invention;

10                   Figure 4 is an end view of Figure 3;

Figure 5 is a cross-sectional view taken along section line 5-5 of Figure 4;

Figure 6 is a cross-sectional view taken along section line 6-6 of Figure 4; and

Figure 7 schematically illustrates another alternative exhaust system.

### 15                   **Detailed Description**

One inventive aspect of the present disclosure relates to a technique for varying the rate at which fuel is dispensed/delivered into the transient flow of an exhaust system. The technique involves using a mathematical model representative of the exhaust system to determine fuel delivery rates suitable for achieving desired results taking into consideration the operating conditions of the system on a real time basis. By 20 using a mathematical model, the fuel delivery rate can be quickly modified in response to variations in the operating conditions of the exhaust system without requiring a large amount of testing as might be required by a strictly empirical modeling approach. To enhance the speed and flexibility of the mathematical model, the model preferably relies 25 upon a relatively small number of inputs (e.g., provided by sensors or other inputs) determined to have the most substantial effect on the operating conditions of the exhaust system. The effects of other variables can be incorporated into the model. Thus, the system can effectively operate with a fewer number of input sources.

Another inventive aspect of the present disclosure relates to a system for 30 regenerating a diesel particulate filter. The system includes a fuel supply device



positioned upstream from the diesel particulate filter. A controller controls the rate fuel is dispensed by the fuel supply device. The controller interfaces with input sources that provide data representative of characteristics of the exhaust gas being conveyed through the exhaust system. Based on the characteristics of the exhaust gas, the controller

5 causes the fuel supply device to dispense fuel into the exhaust stream at a rate sufficient to cause the controlled regeneration of diesel particulate filter. In one embodiment, the fuel supply device is positioned upstream from a catalytic converter (DOC) that is positioned upstream from the diesel particulate filter. The diesel particulate filter may or may not include a catalyst. The desired fuel injection rate is preferably selected such

10 that when the fuel combusts within the catalytic converter, the temperature of the exhaust gas exiting the catalytic converter and traveling to the diesel particulate filter is in the range of 500 to 700°C. In a more preferred embodiment, the temperature of the exhaust gas exiting the catalytic converter is in the range of 550 to 650°C. In a most preferred embodiment, the gas exiting the catalytic converter is about 600°C.

15 In a preferred embodiment, the above-described controller uses a mathematical model to determine the appropriate fuel injection rate for achieving a temperature at the diesel particulate filter that is suitable for causing regeneration of the diesel particulate filter without damaging the diesel particulate filter. For example, the controller can use a model based on a transient energy balance equation for a control

20 volume that includes the DOC. By accessing a relatively small amount of data from the exhaust system (e.g., exhaust temperature entering the control volume, exhaust temperature exiting the control volume, and mass flow through the control volume), the controller can use the model to determine the appropriate rate for fuel to be injected into the system to achieve the desired regeneration temperature. Preferably, the model can

25 take into account the effects of fuel preparation (e.g., fuel vaporization efficiency), DOC performance (e.g., DOC hydrocarbon conversion efficiency) and DOC thermal responses (e.g., DOC energy transfer rates).

In alternative embodiments, the fuel injector can inject fuel directly into the diesel particulate filter without having a preheating process provided by combustion

30 within an upstream catalytic converter. In such embodiments, the fuel ignites with the



catalyst on the diesel particulate filter thereby causing oxidation of the particulate matter on the filter.

# I. Example System

Figure 1 illustrates an exhaust system 20 having features that are examples of inventive aspects in accordance with the principles of the present disclosure. The system includes an engine 22 (e.g., a diesel engine), a fuel tank 24 for supplying fuel (e.g., diesel fuel) to the engine 22, and an exhaust conduit 26 for conveying exhaust gas away from the engine 22. The system 20 also includes a catalytic converter 28 (i.e., DOC) and a diesel particulate filter 30 positioned along the conduit. The catalytic converter 28 is preferably positioned upstream from the diesel particulate filter 30. The system further includes a fuel supply device 32 and a controller 34 for controlling the rate in which fuel is dispensed (e.g., injected or sprayed) into the exhaust stream by the fuel supply device 32. In one embodiment, the fuel supply device may include a fuel injector and one or more spray nozzles.

The fuel supply device 32 preferably inputs fuel at a location between the catalytic converter 28 and the engine 22. Preferably, the fuel supply device 32 inputs fuel to the conduit 26 at a location immediately upstream from the catalytic converter 28. In one embodiment, fuel is supplied to the exhaust stream at a location within 36 inches of the catalytic converter 28. In another embodiment, the fuel is supplied at a location within 12 inches of the catalytic converter.

The fuel supply device 32 is used to spray fuel from the fuel tank 24 into the exhaust stream traveling through the conduit 26 at a location upstream from the catalytic converter 28. The fuel supplied by the fuel supply device 32 combusts within the catalytic converter 28 thereby generating heat. The heat generated by combustion of fuel within the catalytic converter 28 preferably raises the temperature of the exhaust gas exiting the catalytic converter 28 to a temperature above the combustion temperature of the particulate matter accumulated on the diesel particulate filter. In this manner, by burning fuel in the catalytic converter, sufficient heat is generated to cause regeneration of the diesel particulate filter. Preferably, the rate that fuel is dispensed into the exhaust stream is also controlled to prevent temperatures from exceeding levels which may be detrimental to the diesel particulate filter.

It will be appreciated the catalytic converter 28 and the diesel particulate filter function to treat the exhaust gas that passes through the conduit 26. Other structures for treating the exhaust gas such as mufflers for attenuating noise, SCR catalysts, lean NOx catalytic converters and NOx traps/absorbers can also be provided along the conduit 26.

## II. Controller

The controller 34 functions to control the rate that fuel is dispensed by the fuel supply device 32 a given time to cause regeneration of the diesel particulate filter 30. The controller 34 interfaces with a number of sensing devices or other data inputs that provide data representative of the exhaust gas traveling through the conduit 26. For example, the controller 34 interfaces with a first temperature probe 36 positioned upstream of the catalytic converter 28 and a second temperature probe 38 positioned between the catalytic converter 28 and the diesel particulate filter 30. The controller 34 also interfaces with first, second, third and fourth pressure sensors 40-43. The second pressure sensor 41 is located at a venturi 44 positioned within the conduit 26 at a location upstream from the catalytic converter 28. The first pressure sensor 40 as well as the first temperature probe 36 are located upstream of the venturi 44. The third pressure sensor 42 is located between the catalytic converter 28 and the diesel particulate filter 30. The fourth pressure sensor 43 is located downstream of the diesel particulate filter 30.

The venturi 44 has a known cross-sectional area  $A_v$ , and the pressure readings from pressure sensors 40, 41 allow a mass flow rate through the conduit 26 to be determined. It will be appreciated that other types of mass flow sensors other than the venturi and pressure sensors could also be used. Mass flow can also be determined by other means such as accessing data from an engine controller that is indicative of the operating condition of the engine, measuring engine operating characteristics or through the use of a mass flow sensor positioned at the engine intake. Example engine operating characteristics include engine speed (e.g., rotations-per-minute), manifold absolute pressure and manifold temperature. Other engine characteristics include the displacement amount per engine rotation as well as the volumetric efficiency of the

engine. Based on the operating conditions of the engine, the mass flow can be calculated or estimated.

As described below, the controller 34 can use information provided from the pressure sensors 40-43, temperature probes 36, 38 or other inputs to determine the rate that fuel should be dispensed into the exhaust gas stream to regenerate the diesel particulate filter 30 in a controlled manner. In one embodiment, the controller accesses data from the pressure sensors 40-42, and also accesses temperature data from the probes 36, 38. The venturi 44 allows mass flow through the system to be determined. The accessed data is preferably input by the controller into a mathematical model of the actual exhaust system. By using the mathematical model, the controller determines the appropriate rate for dispensing fuel to raise the exhaust gas temperature reaching the diesel particulate filter to a level conducive for regeneration without exceeding a temperature that would be detrimental to the diesel particulate filter..

To promote a controlled and efficient regeneration of the diesel particulate filter 30, it is desirable for the temperature of the exhaust gas exiting the catalytic converter 28 to have a target temperature in the range of 500 to 700°C, as indicated above. Thus, the rate that fuel is dispensed upstream of the catalytic converter 28 is preferably selected so that upon combustion of the fuel within the catalytic converter 28, the exhaust gas exiting the catalytic converter is within the target temperature range.

The controller 34 can also be used to determine when the diesel particulate filter is in need of regeneration. Any number of strategies can be used for determining when the diesel particulate filter should be regenerated. For example, the controller can regenerate the filter 30 when the pressure sensors indicate that the back pressure exceeds a predetermined level. The controller 34 can also regenerate the filter 30 at predetermined time intervals. The controller can also be programmed to delay regeneration if conditions of the exhaust system are not suitable for regeneration (e.g., if the exhaust flow rate or exhaust temperature is not suitable for controlled regeneration). For such an embodiment, the controller can be programmed to monitor the operating conditions of the exhaust system and to initiate regeneration only when predetermined conditions suitable for regeneration have been satisfied.



### III. Diesel Particulate Filter

The diesel particulate filter 30 can have a variety of known configurations. An exemplary configuration includes a monolith ceramic substrate having a "honey-comb" configuration of plugged passages as described in United States patent No. 4,851,015 that is hereby incorporated by reference in its entirety. Wire mesh configurations can also be used. In certain embodiments, the substrate can include a catalyst. Exemplary catalysts include precious metals such as platinum, palladium and rhodium, and other types of components such as base metals or zeolites.

The diesel particulate filter 30 preferably has a particulate mass reduction efficiency greater than 75%. More preferably, the diesel particulate filter has a particulate mass reduction efficiency greater than 85%. Most preferably, the diesel particulate filter 30 has a particulate mass reduction efficiency equal to or greater than 90%. For purposes of this specification, the particulate mass reduction efficiency is determined by subtracting the particulate mass that enters the filter from the particulate mass that exits the filter, and by dividing the difference by the particulate mass that enters the filter.

### IV. Catalytic Converter

The catalytic converter 28 can have a variety of known configurations. Exemplary configurations include substrates defining channels that extend completely therethrough. Exemplary catalytic converter configurations having both corrugated metal and ceramic substrates are described in United States patent No. 5,355,973, that is hereby incorporated by reference in its entirety. The substrates preferably include a catalyst. For example, the substrate can be made of a catalyst, impregnated with a catalyst or coated with a catalyst. Exemplary catalysts include precious metals such as platinum, palladium and rhodium, and other types of components such as base metals or zeolites.

In one non-limiting embodiment, the catalytic converter 28 can have a cell density of at least 200 cells per square inch, or in the range of 200-400 cells per square inch. A preferred catalyst for the catalytic converter is platinum with a loading level greater than 30 grams/cubic foot of substrate. In other embodiments the precious

metal loading level is in the range of 30-100 grams/cubic foot of substrate. In certain embodiments, the catalytic converter can be sized such that in use, the catalytic converter has a space velocity (volumetric flow rate through the DOC/ volume of DOC) less than 150,000/hour or in the range of 50,000-150,000/hour.

5

#### V. Determination of Fuel Dispensing Rate

In accordance with an inventive aspect of the present disclosure, a control equation for determining the rate for fuel to be dispensed into the system by the fuel supply device 32 can be derived using a transient energy balance equation for a given control volume. In the present disclosure, a control volume CV is selected that includes an upstream end 50 positioned upstream from the venturi 44, and a downstream end 51 positioned between the catalytic converter 38 and the diesel particulate filter 30.

15

The transient energy balance equation is applied to the control volume as follows:

20

$$\begin{matrix} (A) & (B) & (C) & (D) & (E) \\ \frac{\partial}{\partial t}(\rho c_p T) + \frac{\partial}{\partial x}(\rho u c_p T) = \frac{\partial}{\partial x_i} \left( k \frac{\partial T}{\partial x_i} \right) + S_f / V_{cv} + S_{DOC} / V_{cv} \end{matrix} \quad (1)$$

5 where

A is the time rate of change of energy within the control volume CV per unit volume;

10 B is the net energy flow per unit volume carried by the mass flow leaving the control volume CV;

C is the net energy flow per unit volume carried by conduction entering through side walls 53 of the control volume CV;

15

D is the heat release rate per unit volume of fuel injected by the fuel supply 32 and combusted at the catalytic converter 38; and

20 E is the heat energy transfer rate per unit volume between the catalytic core of the catalytic converter 28 and the mass flow.

In solving the equation, it will be appreciated that:

$$25 \quad S_f = \eta_{vap} \eta_c h_l \dot{m}_f \quad \text{Heat release rate of fuel injected} \quad (2)$$

$$S_{DOC} = -hA_{DOC}(T_{gas} - T_{DOC}) \quad \text{Heat transfer rate between gas and DOC} \quad (3)$$

$$30 \quad S_{DOC} = -\frac{\partial}{\partial t}(\rho_{DOC} V_{DOC} c_{pDOC} T_{DOC}) \quad \text{Rate of energy change in DOC} \quad (4)$$



Then, combining (1), (2) and (3), ignoring term C in (1)<sup>1</sup> and integrating over the control volume:

$$\frac{[(\bar{\rho}_{cv} V_{cv} c_p \bar{T}_{cv})_n - (\bar{\rho}_{cv} V_{cv} c_p \bar{T}_{cv})_{n-1}]}{\Delta t} + [(\rho_2 Q_2 c_p T_2) - (\rho_1 Q_1 c_p T_1)] = \eta_{vap} \eta_c h_l \dot{m}_f - h A_{DOC} (T_{gas} - T_{DOC}) \quad (5)$$

5

since

$$\bar{\rho}_{cv} = \frac{\bar{P}_{cv}}{R \bar{T}_{cv}} \quad (6)$$

10

we arrive at the following expressions when solving for the required fuel mass flow

$$\dot{m}_f = \frac{\left\{ \left[ \frac{(\bar{P}_{cv} V_{cv} c_p)_n - (\bar{P}_{cv} V_{cv} c_p)_{n-1}}{R \Delta t} \right] + [(\dot{m}_2 c_p T_{2_{doc}}) - (\dot{m}_1 c_p T_1)] + h A_{DOC} (T_{gas} - T_{DOC}) \right\}}{\eta_{vap} \eta_c h_l} \quad (7)$$

15 Further, equating (3) and (4):

$$\frac{m_{DOC} c_{pDOC} (T_{DOC_n} - T_{DOC_{n-1}})}{\Delta t} = h A_{DOC} (T_{gas} - T_{DOC_{n-1}}) \quad (8)$$

20 we obtain the mean DOC temperature

$$T_{DOC_n} = \frac{h A_{DOC} \Delta t}{m_{DOC} c_{pDOC}} (T_{gas} - T_{DOC_{n-1}}) + T_{DOC_{n-1}} \quad (9)$$

where

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<sup>1</sup> For this application, the value C is presumed to be relatively small and therefore can be ignored. For other applications, it may be desirable to include the C value.

Symbols:

	$A_{DOC}$	= DOC flow exposed surface area	[m <sup>2</sup> ]
5	$c_p$	= specific heat	[J/kg·K]
	$h$	= heat transfer coefficient between exhaust gas and DOC	[W/m <sup>2</sup> ·K]
	$h_l$	= fuel lower heating value	[J/kg]
10	$k$	= thermal conductivity	[W/ms]
	$m$	= mass	[kg]
	$\dot{m}$	= mass flow rate of exhaust gas unless indicated otherwise	[kg/s]
	$\dot{m}_f$	= required mass flow rate of fuel	[kg/s]
15	$P$	= pressure	[Pa]
	$Q$	= volumetric flow rate	[m <sup>3</sup> /s]
	$R$	= ideal gas constant for exhaust gas	[J/kg·K]
	$S_f$	= heat release rate of fuel injected	[W]
20	$S_{DOC}$	= heat transfer rate between gas and DOC	[W]
	$T$	= exhaust gas temperature	[K]
	$T_{gas}$	= mean gas temperature in DOC	[K]
	$T_{DOC}$	= mean temperature of DOC substrate	[K]
	$t$	= time	[s]
25	$u$	= velocity	[m/s]
	$V$	= volume	[m <sup>3</sup> ]
	$x$	= coordinate in the axial direction	[m]
	$x_i$	= stands for x, y, z for i = 1, 2, 3	[m]
30	$\Delta t$	= computational time step	[s]

$\rho$  = density  
[kg/m<sup>3</sup>]  
 $\eta_{vap}$  = fuel vaporization efficiency  
 $\eta_c$  = DOC fuel conversion efficiency

5

Suffixes:

$cv$  = control volume  
10  $DOC$  = DOC  
 $des$  = desired (target) value  
 $f$  = fuel  
 $n$  = current time  
 $n-1$  = previous time  
15  $1$  = upstream location of control volume  
 $2$  = downstream location of control volume

By using formula (9), the current temperature of the DOC ( $T_{DOCn}$ ) can be calculated. By inserting the  $T_{DOCn}$  value into the formula (8) along with other sensed  
20 data and known constants, the controller 34 can estimate the fuel dispensing rate required to be supplied into the exhaust stream via the fuel supply device 32 to cause the temperature of the exhaust gas exiting the catalytic converter 28 to equal the target temperature  $T_{2_{des}}$  or to be within a target temperature range. The formula (8) can also be used to construct data matrixes that are used by the controller to determine the fuel  
25 injection rate required to achieve a given target temperature when the exhaust gas has a given set of characteristics as determined by sensors or other inputs.

Attached hereto at Appendix 1 is a chart showing calculated fuel mass flow rate values for example operating conditions. Initially, the fuel flow rate is selected to ramp-up the exhaust temperature exiting the control volume from the  
30 beginning temperature to the target regeneration temperature. Once the target temperature is reached, the fuel mass flow is selected to maintain the target regeneration temperature. As shown at Appendix 1, the only sensed/variable data used by the



controller includes the temperature at the control volume inlet and outlet (provided by probes 36, 38), the pressure at the control volume inlet and outlet (provided by pressure sensors 40 and 42) and the exhaust mass flow rate (provided by pressure reading at the venturi 44 or other means). In addition to the variable data, the controller also uses a number of constant values that are preferably stored in memory. For example, system constant values specific to the control volume (e.g., the volume, mass and surface area of the DOC) can be stored in memory. Other data stored in memory includes application inputs, target temperatures, gas constants for the exhaust gas, and mapped data saved in look-up tables relating to fuel/operating characteristics at given temperatures and pressures such as fuel vaporization efficiency, DOC conversion efficiency and DOC heat transfer coefficient.

## VI. Other Systems

Figure 2 shows an alternative exhaust treatment system 110 for treating the exhaust of a diesel engine 122. The system 110 includes an exhaust conduit 126 for conveying exhaust gas away from the engine 122. A muffler 131 is positioned along the conduit 126. The muffler 131 includes an inlet pipe 133 and an outlet pipe 135. The inlet pipe 133 preferably includes a structure for distributing flow as described in U.S. Patent No. 6,550,573, that is hereby incorporated by reference in its entirety. The inlet pipe 133 is shown clamped to an elbow 137.

A number of structures for treating exhaust gas are positioned within the muffler 131. For example, a diesel particulate filter 30 is shown mounted adjacent the outlet end of the muffler 131. Also, a catalytic converter 28 is mounted within the muffler immediately upstream of the particulate filter 30. Moreover, an optional lean NOx filter 137 is shown mounted within the muffler upstream of the catalytic converter 28.

The exhaust treatment system also includes a fuel injection system for injecting fuel into the exhaust conduit 126 at a location upstream from the catalytic converter 28. As shown in Fig. 2, the fuel injection system includes a nozzle 140 positioned at the elbow 137. The nozzle 140 is adapted to inject a mixture of fuel and air into the exhaust stream. The fuel and air are pre-mixed before reaching the nozzle

140 at a pre-mix region 144 (i.e., a mixing chamber or mixing location). In one embodiment, the fuel pressure is at least 30 pounds per square inch (psi) greater than the air pressure or in the range of 30-50 psi greater than the air pressure. In other embodiments, the fuel pressure is at least 40 psi greater than the air pressure.

5           Air is provided to the pre-mix region 144 from an air tank 146. It will be appreciated that the air tank can be provided by the vehicle air compressor, or can be provided by an auxiliary air compressor (e.g., an electric air compressor). A solenoid valve 147 and an air pressure regulator 148 control air flow to the pre-mix region 144. The air pressure regulator 148 can also provide a filtering function. In certain  
10       embodiments, the air pressure provided to the pre-mix region 144 is in the range of 10-50 psi or 20-40 psi. In other embodiments, the air pressure is about 30 psi.

          Fuel is provided to the pre-mix region 144 from a fuel tank 150 of the engine 122. A fuel pump 152 (e.g., a positive displacement pump) draws fuel from the tank 150. A filter 151 is positioned between the pump 152 and the tank 150, and a fuel  
15       pressure regulator 153 is positioned downstream from the pump 152. The fuel pressure regulator 153 provides fuel to a fuel injector 154 (e.g., a Bosch 280 150 945 injector) for injecting fuel into the pre-mix region 144. In certain embodiments, the fuel pressure provided to the injector 154 is in the range of 40-100 psi or 60-80 psi. In other  
20       embodiments, the fuel pressure is about 70 psi. The pressure regulator 153 is also in fluid communication with a relief circuit 156 that returns flow to the filter 151 which functions as a fuel reservoir.

          The system also includes a controller 170 that controls the fuel injection rate of the fuel injector 154. In the depicted embodiment, the controller receives temperature data from a temperature probe 181 located between the catalytic converter  
25       28 and the diesel particulate filter 30. In certain embodiments, the controller can rely exclusively on the temperature data from the probe 181 (which measures the temperature of the exhaust gas exiting the catalytic converter 28) to determine the rate of fuel to be injected into the exhaust gas stream. In other embodiments, additional data can be used by the controller to determine the fuel injection rate necessary to reach a  
30       target temperature. For example, the controller 170 can access data provided by pressure sensors, and additional temperature sensors as shown in the embodiment of

Fig. 1 or other inputs as previously described. Moreover, mass flow data from other sources such as by accessing data from an engine controller, measuring engine operating characteristics or through the use of a mass flow sensor positioned at the engine intake.

5 Similar to previous embodiments, the controller 170 can use the data described above in concert with a transient energy balance model to determine the rate for fuel to be injected into the system to provide a target regeneration temperature output from the catalytic converter.

10 The controller 170 interfaces with the solenoid valve 147, the fuel pump 152 and the injector 154 to control the rate of fuel dispensed/sprayed by the system.

In a preferred embodiment, valve 147, air pressure regulator 148, filter 151, fuel pump 152, fuel pressure regulator 153, injector 154 and mixing chamber 144 are packaged within a single housing having fuel line connections, air line connections and electrical connections.

15 Figures 3-6 show an example arrangement of the fuel injector 154, the fuel pressure regulator 153 and the pre-mix region 144 of the fuel injection system described above. The arrangement includes injector 154 mounted between fuel regulator 153 and a mixing housing 191. The components can be held together by fasteners such as bolts (not shown) that extend through openings 193 (see Fig. 5) defined by the fuel regulator 153. The fasteners can thread within tapped openings 194 (see Fig. 5) defined by the mixing housing 191. The fasteners also can extend through spacer tubes 195 positioned on opposite sides of the injector 154.

20 Referring to Fig. 6, the injector 154 receives fuel from the regulator 153 and injects the fuel into the pre-mix region 144 defined by the mixing housing 191. The mixing housing 191 defines a first port 191a for supplying air to the pre-mix region 144 and a second port 191b for directing a mixture of air and fuel to the nozzle 140.

Referring still to Fig. 6, the fuel regulator 153 defines a first port 153a for connection to the fuel pump 152 and a second port 153b for connection to the re-circulation line.

30 Figure 7 shows another exhaust treatment system 210 having the same configuration as the system of Figure 2 except the air and fuel of the injection system



are not pre-mixed, but are instead mixed at nozzle 240 as the air and fuel are injected into the exhaust stream. Fuel line 282 supplies fuel to the nozzle 240, and a separate air line 283 provides air to the nozzle 240. The embodiment of Figure 7 preferably includes a purge air line 280 for purging fuel from fuel line 282.

5            In the above embodiments, fuel is injected into the exhaust stream to raise exhaust temperatures to a target temperature suitable for regenerating a diesel particulate filter. In other embodiments, the fuel injection systems disclosed herein can be use to inject fuel into an exhaust stream for other purposes such as to provide hydrocarbons to promote the conversion of NOx at a lean NOx catalyst or to provide  
10 hydrocarbons for regenerating NOx traps. A variety of control models can be used to control fuel injection rates for these alternative systems. Also, while it is preferred to inject fuel into the exhaust stream with a separate injector, other fuel supply techniques such as fuel injection from the engine (e.g., late cycle injection) are also included within the scope of the invention.

15

We claim:

1. A method for injecting fuel into a transient exhaust stream of an exhaust system, the method comprising:  
5 selecting a control volume within the exhaust system; and  
using a model derived from a transient energy balance equation for the control volume to determining the rate for fuel to be dispensed into the exhaust stream.
2. The method of claim 1, wherein the control volume includes a  
10 catalytic converter, wherein the catalytic converter is positioned upstream from a diesel particulate filter, wherein the fuel is dispensed upstream of the catalytic converter, and wherein rate for dispensing the fuel is selected to achieve a temperature at a downstream end of the catalytic converter that is suitable for causing regeneration of the diesel particulate filter without causing the diesel particulate filter to overheat.  
15
3. The method of claim 1, wherein the exhaust system includes a catalytic converter positioned upstream from a diesel particulate filter and a fuel dispensing nozzle positioned upstream from the catalytic converter, and wherein the control volume starts upstream from the fuel dispensing nozzle and ends at the  
20 downstream end of the catalytic converter.
4. The method of claim 1, further comprising accessing pressure, temperature and mass flow data for the exhaust system, and using the data in concert with the model to determine the rate of fuel to be injected.  
25
5. The method of claim 1, wherein the exhaust system includes a catalytic converter positioned upstream from a diesel particulate filter and a fuel injector positioned upstream from the catalytic converter, wherein temperature and pressure data are sensed upstream of the fuel injector and downstream of the catalytic converter, and  
30 wherein the temperature and pressure data are used in concert with the model to

determine a fuel injection rate suitable to reach a temperature at the downstream end of the catalytic converter that is within a target temperature range.

6. The method of claim 2, wherein the model takes into  
5 consideration the vaporization efficiency of the fuel.

7. The method of claim 2, wherein the model takes into  
consideration the fuel conversion efficiency of the catalytic converter.

8. The method of claim 2, wherein the model takes into  
10 consideration the thermal energy storage rate of the catalytic converter.

9. The method of claim 2, wherein the model takes into  
consideration mass flow through the control volume.  
15

10. An exhaust system comprising:  
an exhaust conduit;  
a catalytic converter positioned in the exhaust conduit;  
a diesel particulate filter positioned in the exhaust conduit  
20 downstream of the catalytic converter;  
a fuel injection nozzle positioned upstream from the catalytic  
converter;

a first temperature probe for sensing a gas temperature in the  
exhaust conduit, the first temperature probe being positioned between the  
25 catalytic converter and the diesel particulate filter;

a controller that uses data from the first temperature probe as well  
as mass flow data to determine a rate of fuel to be injected into the exhaust  
conduit by the fuel injection nozzle to reach a temperature at the diesel  
30 particulate filter suitable for causing regeneration.

11. The exhaust system of claim 10, further comprising a second temperature probe located upstream of the fuel injection nozzle.

5 12. The exhaust system of claim 10, further comprising a first pressure sensor located upstream of the fuel injection nozzle and a second pressure sensor located between the catalytic converter and the diesel particulate filter.

10 13. The exhaust system of claim 10, further comprising means for determining mass flow through the exhaust conduit.

14. The exhaust system of claim 10, further comprising a venturi positioned upstream from the catalytic converter.

15 15. The exhaust system of claim 10, wherein the fuel injection nozzle is part of a fuel injection system that includes an air line and a fuel line.

16. The exhaust system of claim 15, wherein the air line and the fuel line mix at the fuel injection nozzle.

20 17. The exhaust system of claim 15, wherein the air line and the fuel line meet at a pre-mix region prior to reaching the fuel injection nozzle.

25 18. The exhaust system of claim 17, wherein a fuel injector injects fuel into the pre-mix region.

30 19. The exhaust system of claim 15, wherein the fuel line includes a filter, a fuel pump, a fuel pressure regulator and a fuel injector positioned in series, and wherein the fuel line includes a relief circuit that extends from the fuel pressure regulator to the filter.



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20. The exhaust system of claim 19, wherein the air line includes an air valve and an air pressure regulator.

21. The exhaust system of claim 20, wherein the filter, the fuel pump, the fuel pressure regulator, the fuel injector, the air valve and the air pressure regulator are mounted within a single housing.

22. An exhaust system comprising:

- an exhaust conduit;
- a fuel injection nozzle for injecting fuel into the exhaust conduit;
- an air line for supplying air to the nozzle;
- a fuel line for supplying fuel to the nozzle; and
- a controller for determining a rate of fuel to be injected into the exhaust conduit.

23. The exhaust system of claim 22, further comprising a pre-mix region in which the air and fuel are mixed prior to reaching the nozzle.

24. The exhaust system of claim 22, wherein the air and fuel are  
20 mixed at the nozzle.

25. The exhaust system of claim 1, further comprising a catalytic converter and a diesel particulate filter positioned within the exhaust conduit, the catalytic converter being positioned upstream of the diesel particulate filter and the nozzle being positioned upstream from the catalytic converter.

26. The exhaust system of claim 25, wherein the controller controls a rate of fuel injected into the exhaust conduit by the fuel injection nozzle to reach a temperature at the diesel particulate filter suitable for causing regeneration.

27. The exhaust system of claim 22, wherein the nozzle is positioned upstream from a lean NO<sub>x</sub> catalyst.

28. The exhaust system of claim 22, wherein the nozzle is positioned upstream from a NOx absorber.

*[Faint, illegible handwritten notes at the bottom of the page.]*



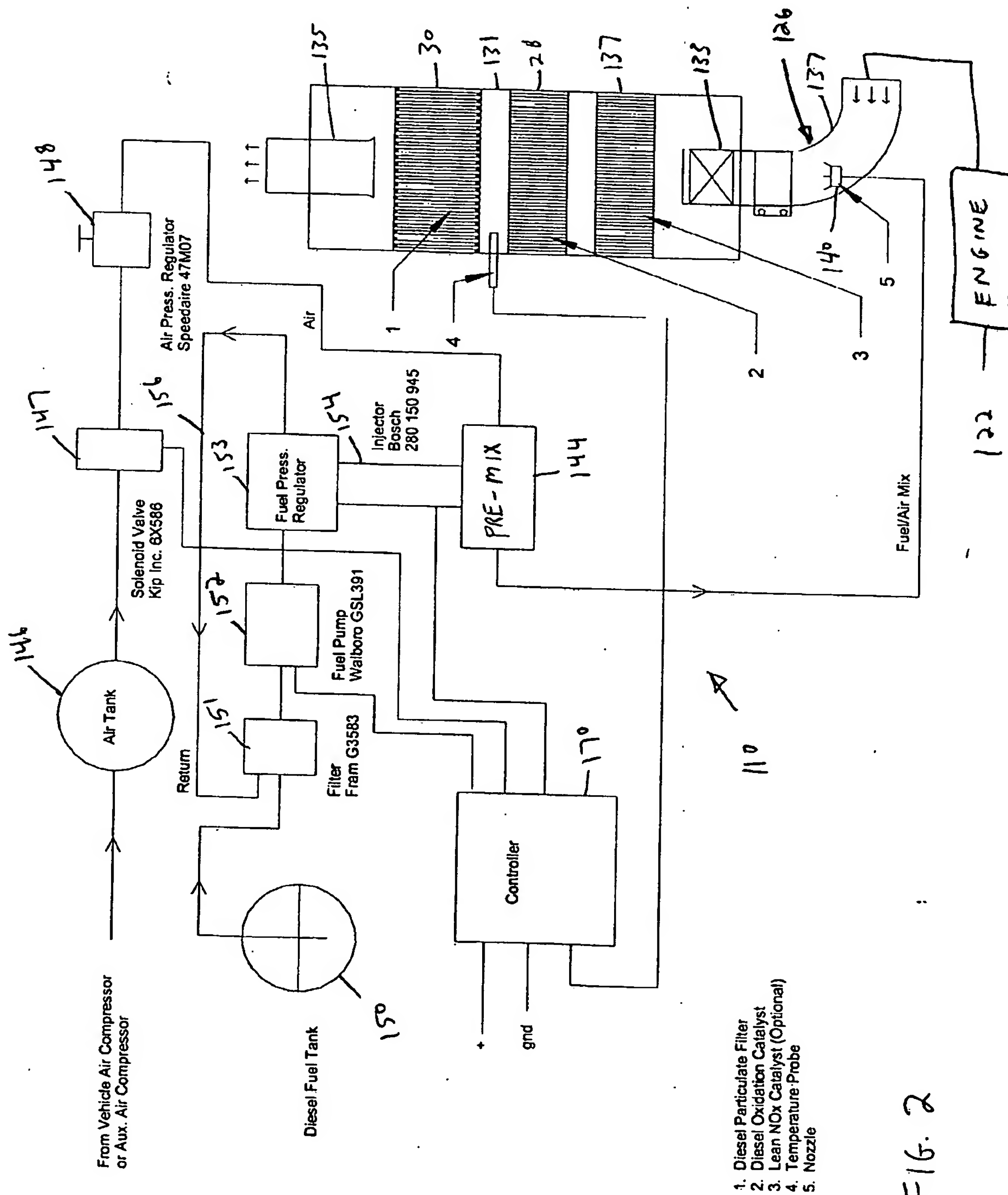


FIG. 2



Inventor: HOU ET AL.  
Docket No.: 758.1509USP1  
Title: METHOD OF DISPENSING FUEL INTO TRANSIENT FLOW OF AN EXHAUST  
SYSTEM  
Attorney Name: DAVID G. SCHMALTZ  
Phone No.: 612.336.4617  
Sheet 3 of 6

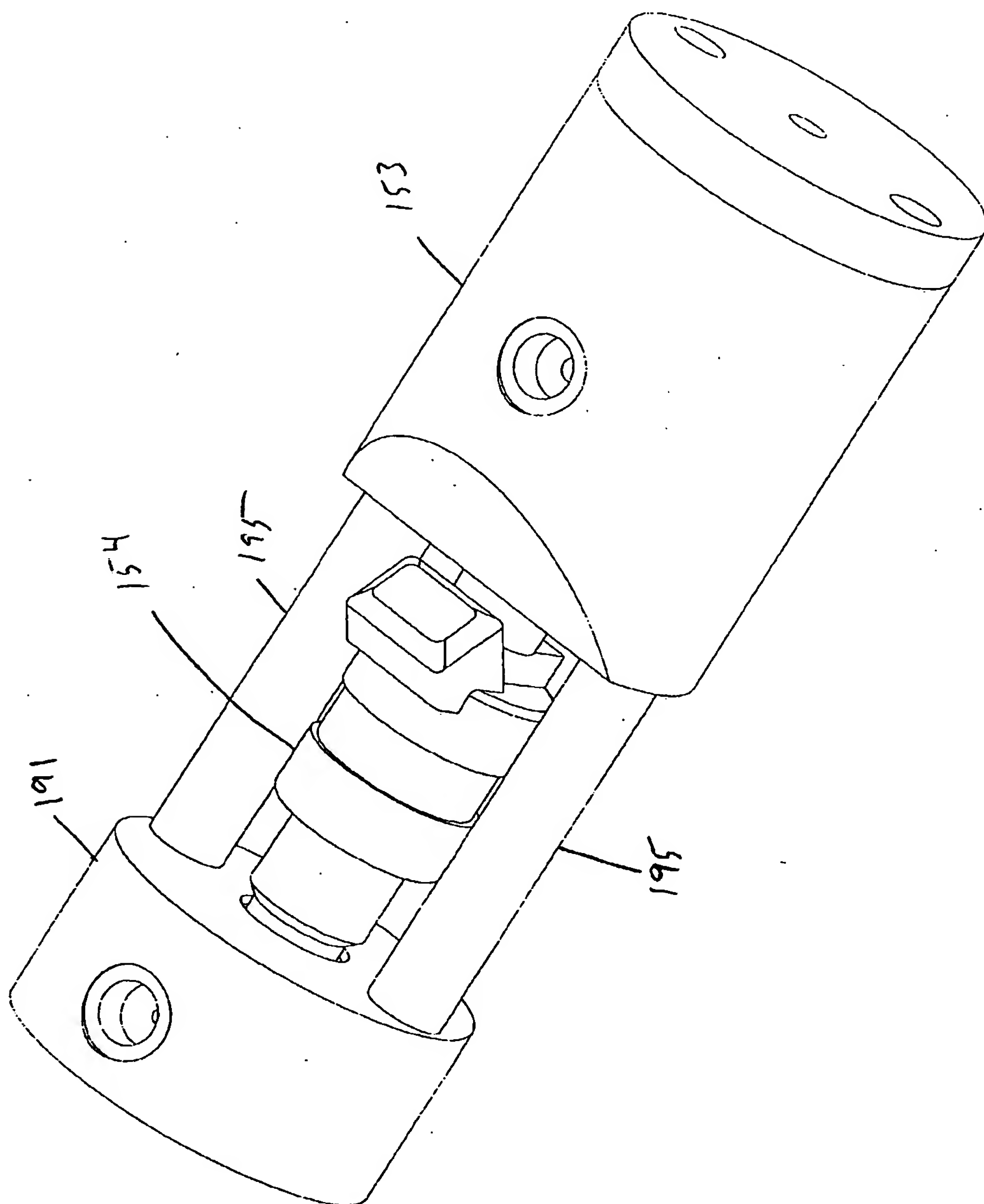


FIG. 3

Inventor: HOU ET AL.  
Docket No.: 758.1509USP1

Title: METHOD OF DISPENSING FUEL INTO TRANSIENT FLOW OF AN EXHAUST  
SYSTEM

Attorney Name: DAVID G. SCHMALTZ

Phone No.: 612.336.4617

Sheet 4 of 6

FIG. 5

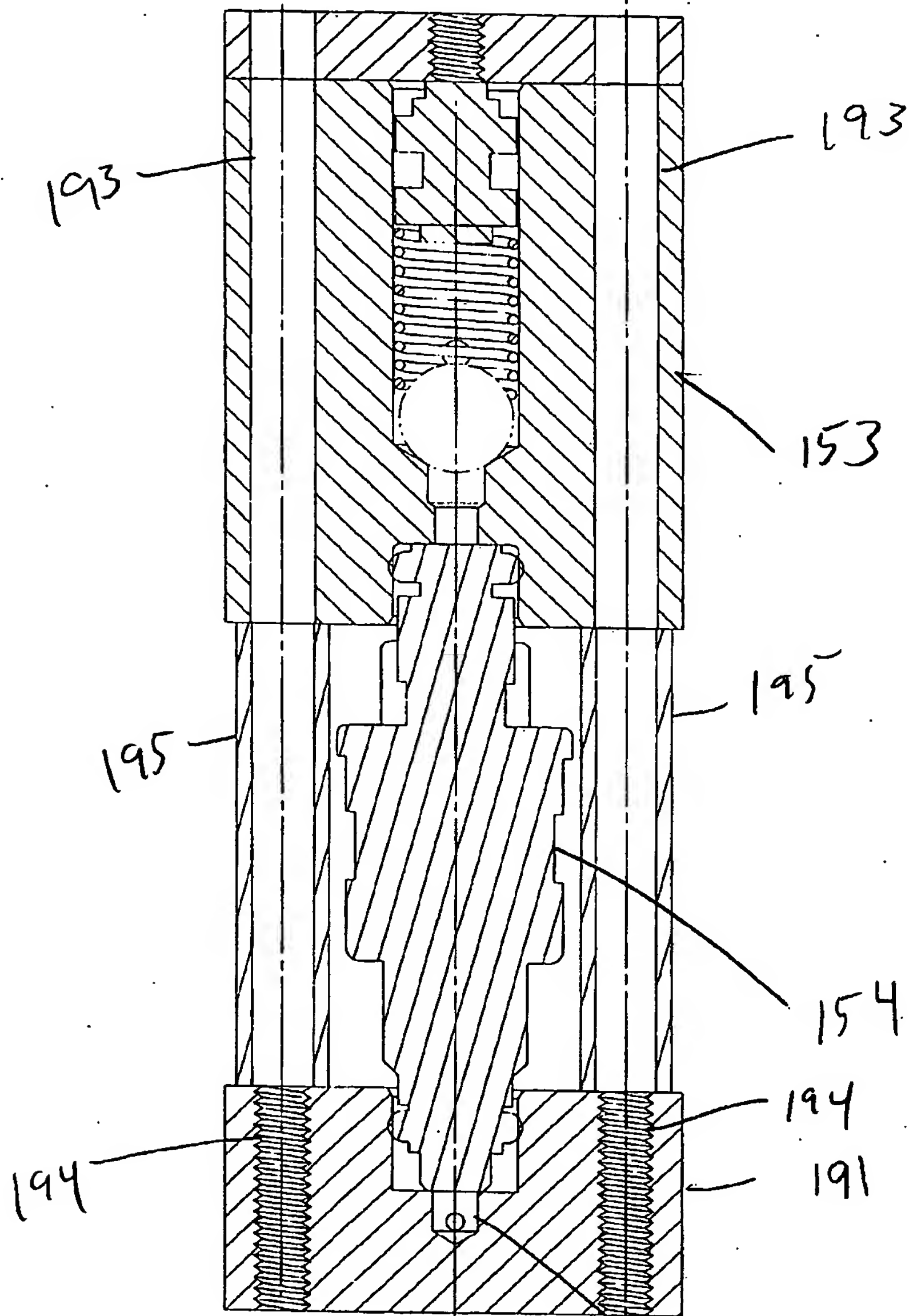
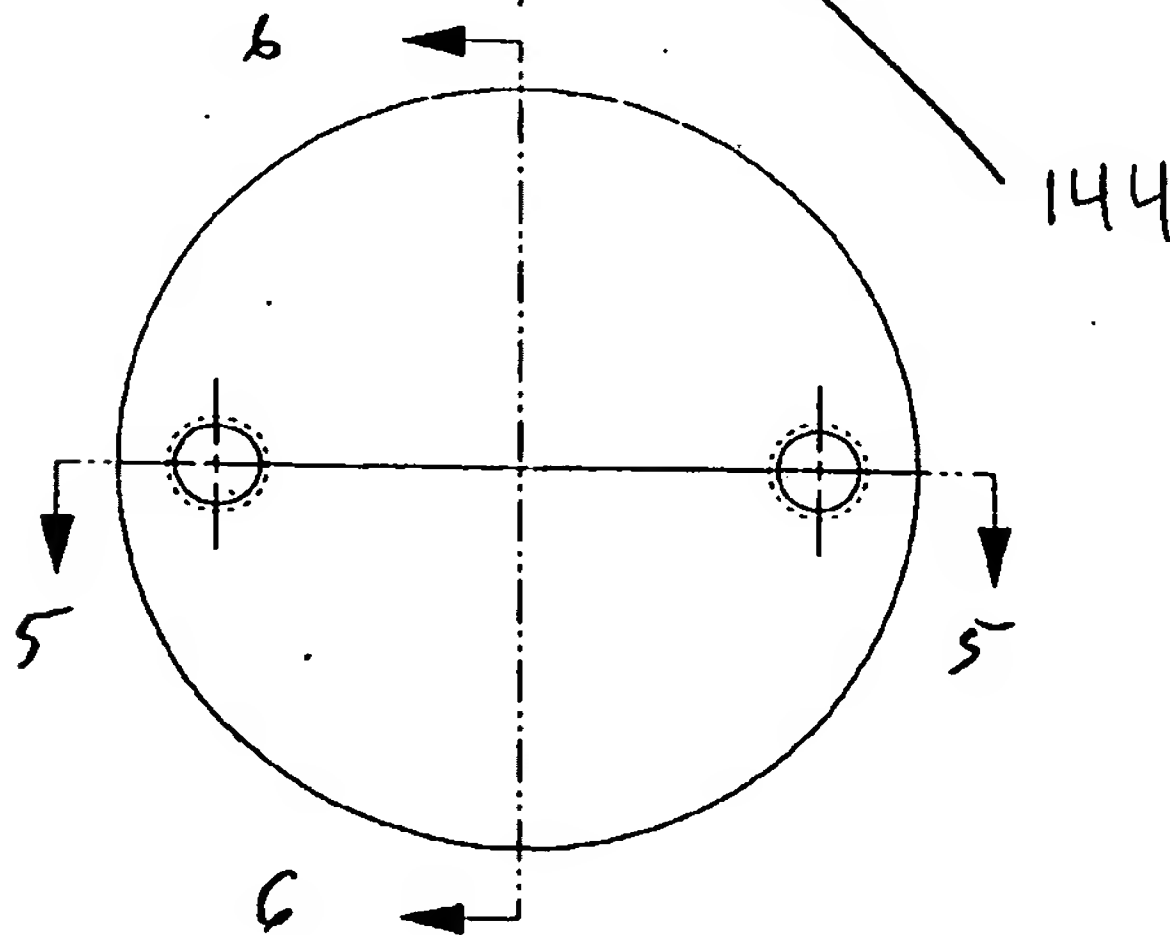


FIG. 4



Inventor: HOU ET AL.  
Docket No.: 758.1509USP1

Title: METHOD OF DISPENSING FUEL INTO TRANSIENT FLOW OF AN EXHAUST  
SYSTEM

Attorney Name: DAVID G. SCHMALTZ

Phone No.: 612.336.4617

Sheet 5 of 6

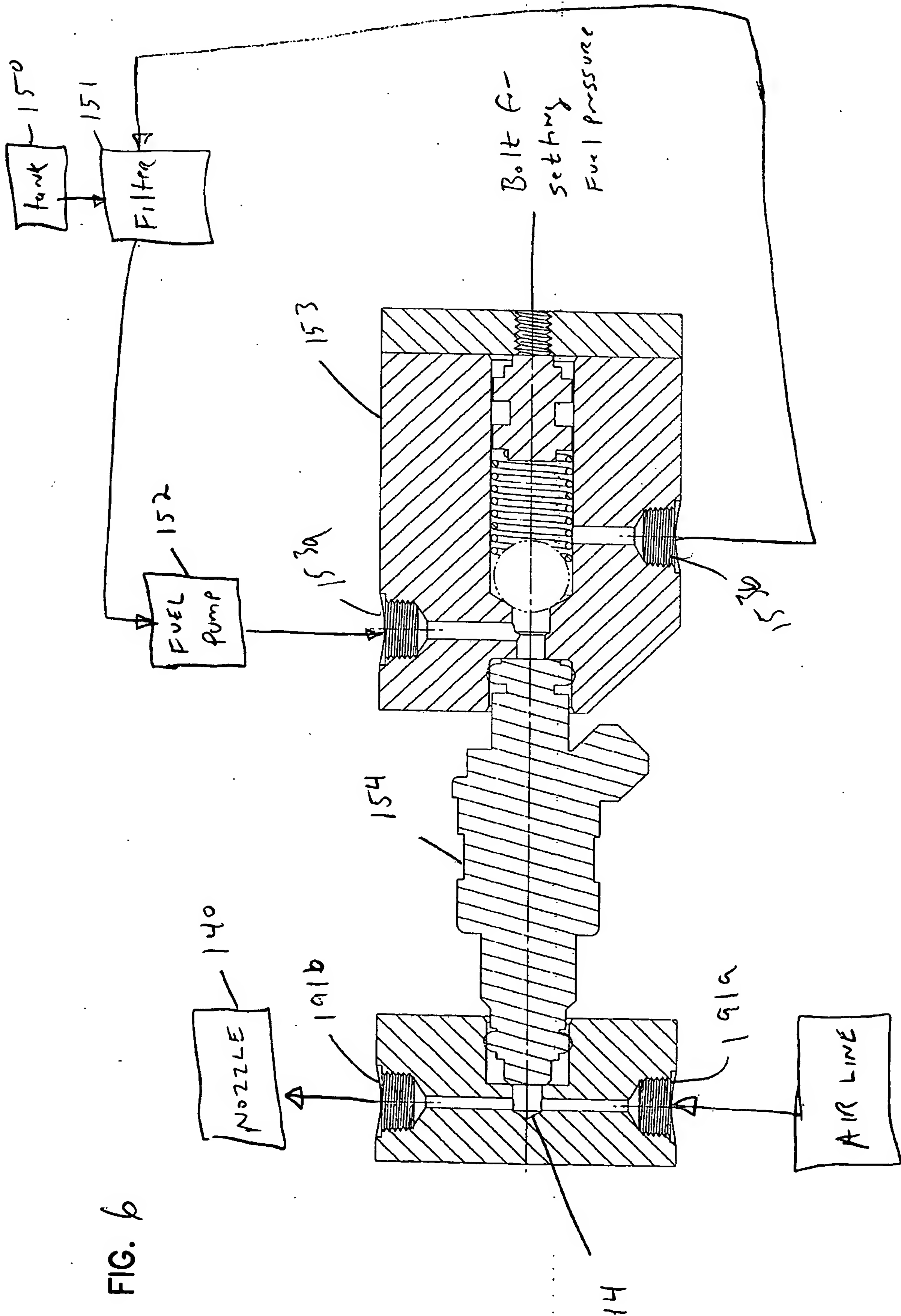


FIG. 6

Sheet 6 of 6





# APPENDIX 1

60478678-06-2013

## Fuel Injection Control Example

Variable	Symbol	Unit	Regen start				Ramp-up			
			Time = 0	Time = 1	Time = 2	Time = 3	Time = 0	Time = 1	Time = 2	Time = 3
System constant										
Volume, control volume	V	m <sup>3</sup>	2.68E-02	2.68E-02	2.68E-02	2.68E-02				
Mass, DOC	M_DOC	kg	2.750	2.750	2.750	2.750				
Surface area, DOC flow exposed	A_DOC	m <sup>2</sup>	20.0	20.0	20.0	20.0				
Application Input										
Lower heating value, fuel	h_l	MJ/kg	43.2	43.2	43.2	43.2				
Time step	Δt	sec	1.0	1.0	1.0	1.0				
Constant										
Gas constant, exhaust gas	R	J/kg-K	286.7	286.7	286.7	286.7				
Sensor read										
Temperature, CV inlet	T_1	deg C	255.0	255.0	255.0	255.0				
Temperature, CV exit	T_2	deg C	250.0	350.0	450.0	550.0				
Pressure, CV inlet	P_1	Pa	7000.0	7500.0	8000.0	8500.0				
Pressure, CV exit	P_2	Pa	6000.0	6500.0	7000.0	7500.0				
Mass flow rate, before injector	m_dot,1	kg/s	0.160	0.160	0.160	0.160				
Target										
Temperature, CV exit	T_2des	deg C	350.0	450.0	550.0	550.0				
Mapped data										
Evaporation efficiency, fuel	η_vap	-	0.90	0.90	0.90	0.90				
Conversion efficiency, DOC	η_c	-	0.50	0.60	0.70	0.75				
Heat transfer coefficient, gas-DOC	h_DOC	W/m <sup>2</sup> -K	10.0	10.0	10.0	10.0				
Calculated data										
Temperature, CV average	T_cv,n	deg C	252.5	302.5	352.5	402.5				
Pressure, CV average	P_cv,n	Pa	107800.0	108300.0	108800.0	109300.0				
Density, CV average	ρ_cv,n	kg/m <sup>3</sup>	7.15E-01	6.56E-01	6.07E-01	5.64E-01				
Specific heat, CV average	C_p,exh,n	J/kg-K	1035.3	1045.7	1056.9	1068.7				
Temperature, CV average @ n+1	T_cv,n+1	deg C	302.5	352.5	402.5	402.5				
Pressure, CV average @ n+1	P_cv,n+1	Pa	107800.0	108300.0	108800.0	109300.0				
Density, CV average @ n+1	ρ_cv,n+1	kg/m <sup>3</sup>	7.49E-01	4.95E-01	3.58E-01	2.94E-01				
Specific heat, CV average @ n+1	C_p,exh,n+1	J/kg-K	1045.7	1056.9	1068.7	1068.7				
Unsteady term			1652.3	-1820.8	-3823.6	-5226.2				
Mass flow rate, CV exit	m_dot,2	kg/s	0.160	0.161	0.162	0.162				
Specific heat, CV inlet	C_p,exh,1	J/kg-K	1035.8	1035.8	1035.8	1035.8				
Specific heat, CV exit	C_p,exh,2	J/kg-K	1056.3	1080.2	1104.2	1104.2				
Convective term			17788.8	38148.9	59497.8	60108.3				
Temperature, mean gas thru DOC	T_gas	deg C	252.5	302.5	352.5	402.5				
Temperature, DOC substrate	T_DOC	deg C	252.5	256.2	263.4	273.7				
Specific heat, DOC substrate	C_p,DOC	J/kg-K	974.3	976.7	981.3	987.7				
Heat sink term			0.0	9253.5	17819.9	25758.1				
Mass flow rate, fuel	m_dot,f	kg/s	1.00E-03	1.95E-03	2.70E-03	2.77E-03				

# APPENDIX 1

20170829 10:21:03

Time = 4 Time = 5

2.68E-02 2.68E-02  
2.750 2.750  
20.0 20.0

43.2 43.2  
1.0 1.0

286.7 286.7

255.0 300.0  
550.0 550.0  
8500.0 12000.0  
7500.0 10000.0  
0.160 0.200

550.0 550.0

0.90 0.95  
0.75 0.85  
10.0 10.0

402.5 425.0  
109300.0 112300.0  
5.64E-01 5.61E-01  
1068.7 1074.1  
402.5 425.0  
109300.0 112300.0  
2.94E-01 2.93E-01  
1068.7 1074.1  
-5226.2 -5396.9

0.162 0.203  
1035.8 1045.2  
1104.2 1104.2  
60161.5 64314.7

402.5 425.0  
283.2 293.6  
993.3 999.2  
23861.5 26285.0

2.70E-03 2.44E-03